Resonant cavities and acoustics vases in Italian Opera Houses; the "Teatro Principal" of Valencia and the eighteenth century treatises about theatres

A. Barba Sevillano[a], A. Giménez[a], R. Lacatis[a] and R. Cibrián[b]

[a]Grup d'Acustica Arquitectònica, Ambiental i Industrial, E.T.S.I.I, Univ. Politécnica de Valencia, Camino de Vera, s/n, 46022 Valencia, Spain
[b]Facultad de Medicina, Univ. de Valencia, Av. Blasco Ibáñez, 15, 46010 Valencia, Spain
arbarse@doctor.upv.es

This paper describes the research job carried out at Polytechnic University of Valencia –Spain- about resonant cavities placed under the orchestra pits of Italian Opera Houses, and others acoustics mechanisms like this one.
The *Teatro Principal* of Valencia was built following the Project developed by the Italian architect Felipe Fontana in 1774 and it opened its doors in 1832. Fifteen years ago, in the last architectonic intervention in this theatre, almost a hundred of acoustic vases were found in one of those resonant cavities. What acoustics role they accomplish? How they "functioned"?
This was the starting point to study this kind of artifices, throughout the eighteenth century European treatises about theatres and in our *Teatro Principal*.

1 Introduction

The Teatro Principal is one of the Valencia's most emblematic halls (Spain). It has been unquestionably the musical and theatre reference point in the region for more than 150 years, this is, from its inauguration in 1.832 until the appearance in 1.987 of the "Palau de la Música de Valencia", designed and built by architect J. Mª García de Paredes.
The Teatro Principal is one of Spain´s first horseshoe shaped theatres (We shall remember that the "Teatro Real" of Madrid was inaugurated in 1.850 and the "Gran Teatre del Liceu" of Barcelona in 1.847). Moreover, its main hall has remained until nowadays without any important changes in its architectonic structure.

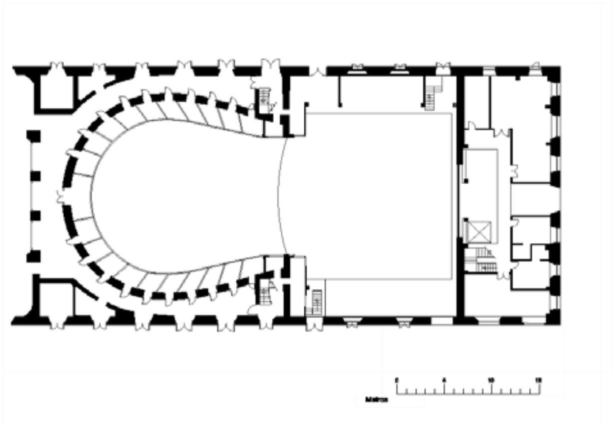

Figure 1- Teatro Principal of Valencia: first floor plan

These reasons leaded us to carry out a deep study about the acoustics of this theatre last year. Under the orchestra pit and probably in order to reinforce the sound of the orchestra, an air chamber was made in the 19th century in which there are located a hundred of invested perforated vessels. Our interest about these vessels was the starting point to begin the research that we are going to explain in this paper.

2 Teatro Principal of Valencia: acoustics study

2.1 Italian Opera Houses

Although the beginning of the architectural typology of the Italian Opera Houses (Theatre with a horseshoe, oval or ellipse shaped ground floor plan, and theatre boxes around it*)* goes back to the baroque period, it will not be until the 18^{th} and mainly 19^{th} centuries when it reaches its apogee, due to a greater demand from the mighty European bourgeoisie. From their birth, these halls changed very little because there was an objective limit on its dimensions: which was the limit of demanding an acceptable hearing and visibility.
The Italian Opera House typology admitted, since the beginning, multiple variants in the plant design. Thus, different shape theatres were created from the initial U-shaped ones.
The elliptical shape was considered by lot of architects as the more convenient in order to obtain an adequate acoustic design. It was adopted in important theatres such as the Tordinona Theatre in Rome (1670), the Regio Theatre in Torino (1738-1740) or the Versailles Opera Theatre.

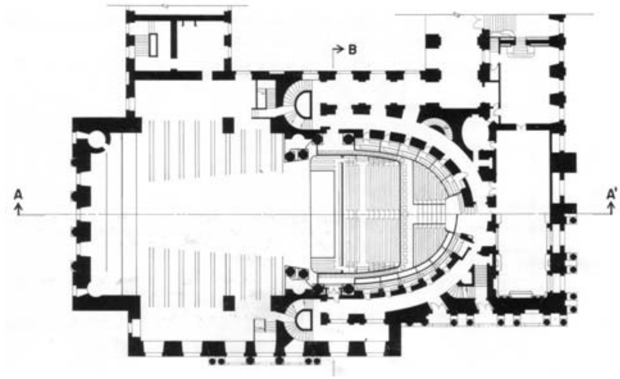

Figure 2. Elliptical ground floor of the Versailles Opera Theatre. (Jacques-Ange Gabriel)

Another important shape was the circular one, adopted by the architect Benjamin Dean Wyatt (1746-1813) for the Theatre Royal Drury Lane (1811) in London, and supported by the researcher G. Saunders [1]

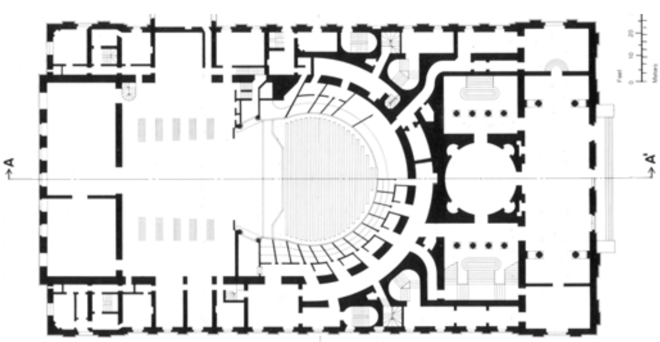

Figure 3. Circular ground floor of the Theatre Royal Drury Lane (1811)

The bell-shape was another of the plant shapes more adopted along the 17^{th} and 18^{th} centuries.

2.2 The Teatro Principal: Architectonic Characteristics

The Teatro Principal of Valencia was built following the project developed by the Italian architect Felipe Fontana in 1.774, and it was inaugurated on 24 of July 1.832. The theatre comprises a seating capacity of 1.226 localities distributed in stalls, two tiers of boxes and two upper galleries. The theatre has a "stage box" of 8.202 m3, 24.60 m. width, 17.55 m. depth and 19.00 m. height, facing a horseshoe shaped capacity area of 6.570 m3, 21.80 m. length and a maximum height of 15.95 m. The theatre has two lower floors underneath the stage, and an orchestra pit. Under this orchestra pit and probably in order to reinforce the sound of the orchestra, an air chamber was made in the 19th century in which there are located a hundred of invested perforated vessels.

2.3 Acoustics simulation of the theatre

Firstly, we carried out acoustics measurements in situ, in the theatre. Then, after knowing the values of the acoustics parameters from the experimental tests, we developed a geometric model of the theatre and we used a system of acoustic simulation (CATT-Acoustic v-8 software) to predict the theatre's acoustic field's behaviour considering any changes that could take place in the hall's shape. Coefficients of absorption and diffusion obtained of specialized bibliography were assigned to every surface of the theatre. [2]

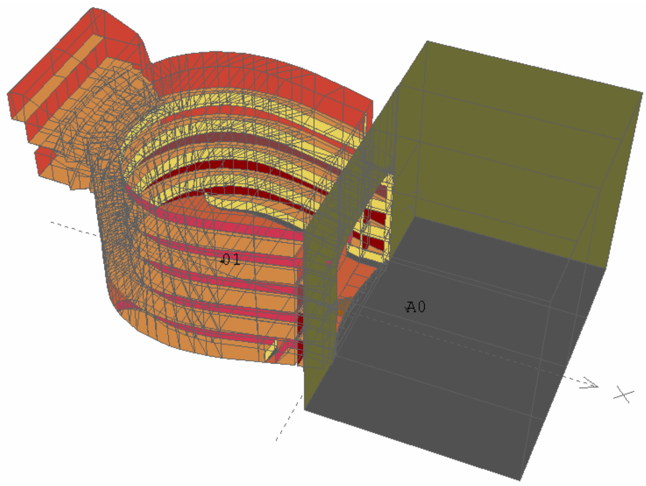

Figure 4. Teatro Principal of Valencia:
3D Geometric model [2]

Finally we adjusted the geometric model by an iterative procedure based on the adjustment of the coefficients of absorption and diffusion for the materials that do not appear in bibliography and whose testing is excessively complex in the laboratory (The parameters studied for the geometric model's adjustment has been Reverberation Time (RT), and the Strength (Gmid)).

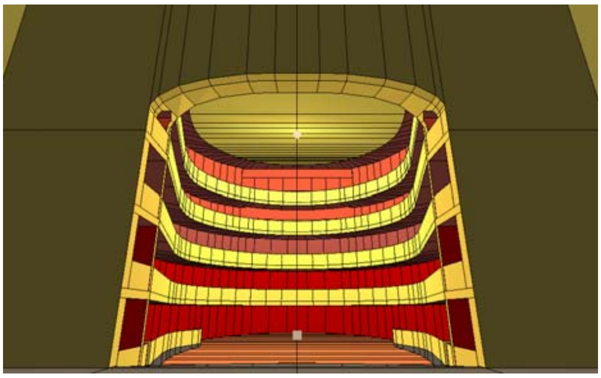

Figure 5. Teatro Principal of Valencia:
3D Geometric model

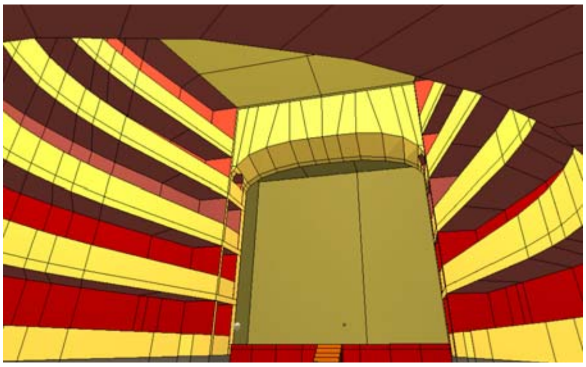

Figure 6. Teatro Principal of Valencia:
3D Geometric model

2.4 The vessels

Twenty years ago, when the architect G. Stuyck carried out in the Teatro Principal an architectonic intervention a hundred of invested perforated vessels (as clay pots) were found in an interesting air chamber under the orchestra pit (figures 7-8). This vessels are approximately 40 cm height. The architect didn't know their possible acoustics function and decided to restore the air chamber and replaced the broken vessels (half a dozen). Then, a new wooden floor over this chamber was made.

Figure 7. Air chamber with the clay vessels, under the orchestra pit (1989 picture [3])

Figure 8. Air chamber with the clay vessels, under the orchestra pit (1989 picture [3])

The original acoustic function of these vessels is a mistery for us nowadays. Firstly we thought that the vessels could be used as "Helmholtz simple resonators" [4]. Their effect would be a big absorption in the resonant frequency (very big absorption, because there are a hundred of vessels).

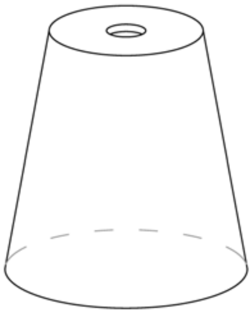

Figure 9. Clay vessel similar as the found in the theatre, but only with one perforation.

However, the vessels of the Teatro Principal have not only one perforation. They have seven ones (figure 10). That's why we considered that the vessels were not functioning as absorbent resonators.

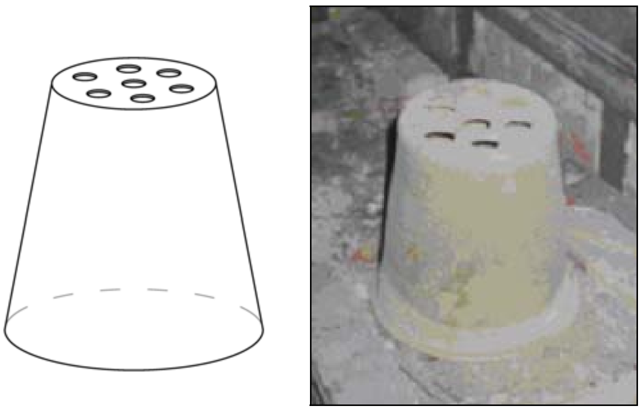

Figure 10. Drawing and picture ([3] 1989) with a found clay vessel.

All the found vessels has the same number of perforations (seven) and the same dimensions. As there are almost a hundred of elements.

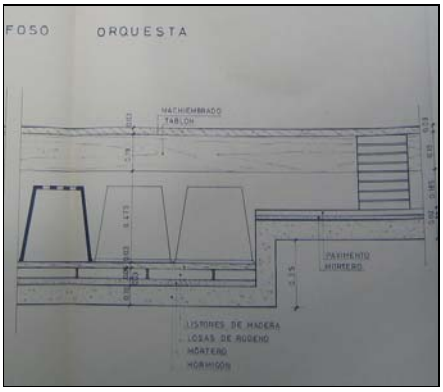

Figure 11. Resonance chamber and vessels under the orchestra pit. Drawn by G. Stuyck, (1989) [3]

The issue of vessels and the air chamber under the orchestra pit interested us greatly, we began a detailed search of the literature looking for this find of acoustics mechanisms.

3 Bibliographic search on Theaters

3.1 Semicylindrical air chambers

The presence of a resonance chamber in order to amplify the sound of the orchestra (under the orchestra pit or under the ground floor seats) was quite common in the opera houses of the eighteenth century, especially in Italian ones.
The famous French researcher Pierre Patte (1723-1814) in his *Essai sur l'architecture thêatrale* [5] explains that the Teatro Regio in Turin was under the wooden floor of the orchestra pit a semicylindrical air chamber. Two conduits connected this chamber with the stage (figures 12-14). The objective of this mechanism was on the one hand reflect and reinforce the sound of the orchestra due to the hardness of material of the semicylindrical chamber and to its curve form; and on the other hand this air chamber helped the resonance of the wooden floor of the orchestra pit. Patte incorporated this acoustic mechanism in the ideal "salle de spectacle" designed by himself in his *Essai sur l'architecture théatrale* (Figure…….).

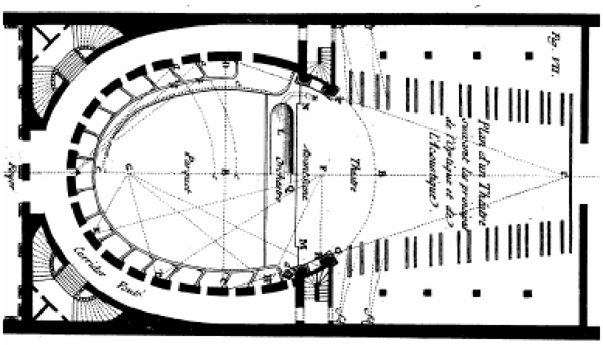

Figure 12. "Plan d'un Théatre suivant les principes de l'Optique et de l'Acoustique", ideal opera house by Pierre Patte (Paris, 1782, [5] 211 Fig. VII)

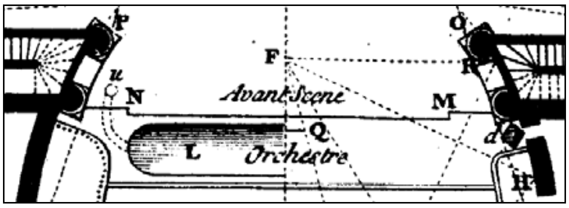

Figure 13. Ideal opera house by P. Patte [5]. Detail of the acoustic chamber plant

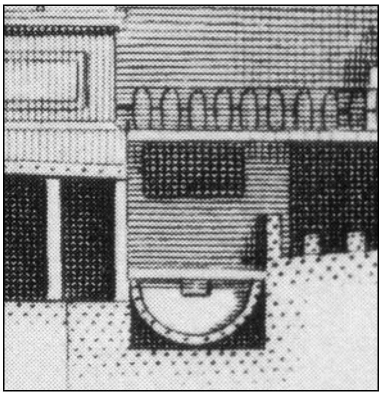

Figure 14. Ideal opera house by P. Patte. Section : detail of the semicylindrical chamber under the orchestra pit floor ([6] by Forsyth)

We can find a similar semicylindrical air chamber in other of the most important treatises about theatres in the eighteenth century: the “Treatise on Theatres” written by the Englishman George Saunders, and published in 1790 [1]. Like Patte, Saunders proposes an "ideal" opera theatre. The figures 15 and 16, show clearly the chamber located under the pavement of the orchestra pit.

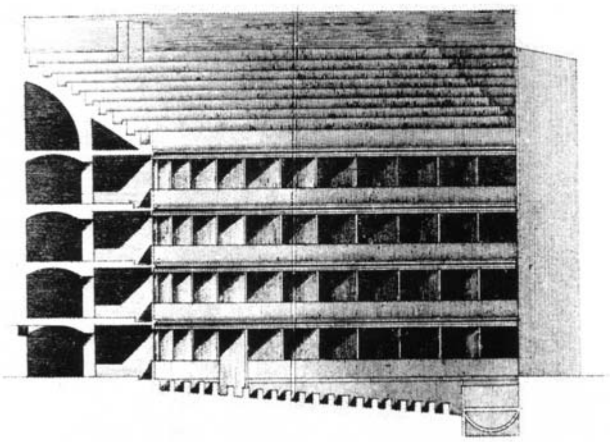

Figure 15. G. Saunders: ideal opera house; longitudinal section [1]

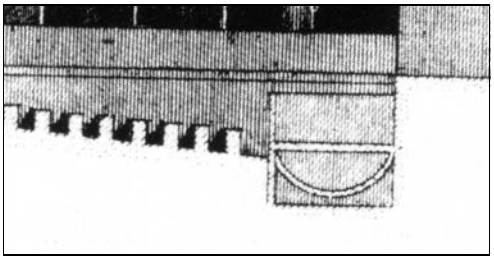

Figure 16. G. Saunders: ideal opera house; longitudinal section [1] : detail of the semicylindrical chamber under the orchestra pit floor

The design of an ideal opera house has been from 18th century a very interesting task for theoretical architects. In the 19th century, the visionary French architect N. Ledoux designed an elaborate theatre for Besançon (France). He draws a very ingenious orchestra pit (figures 17-18) :

- there is a semicylindrical air chamber under the pit floor, as Patte or Saunders had designed a century before.

- the interior wall of the pit has semicircular form, in order to send reflections directly over the public.

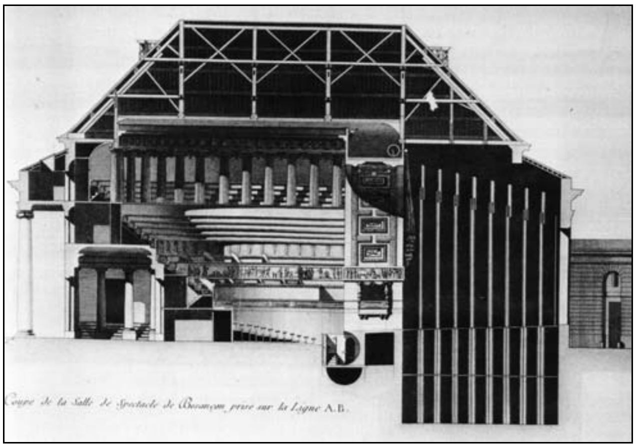

Figure 17. N. Ledoux: Besançon Theatre design; longitudinal section (L’Architecture considérée sous le rapport de l’art, Claude-Nicolas Ledoux, París, 1804) ([6] by Forsyth)

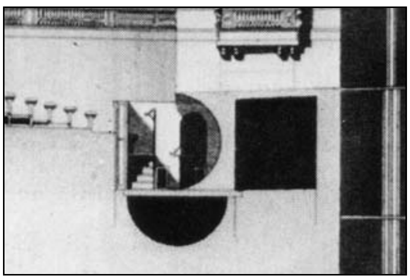

Figure 18. N. Ledoux: Besançon Theatre design; longitudinal section. Detail ([6] by Forsyth)

5 Conclusion

With this work we think to have contributed to extend understanding of the Italian Opera Houses.

We have investigate about air chambers under the orchestra pits in Opera Theatres, but we have not carried out acoustics measurements of its effect. With this paper we hope to encourage another researchers to study this kind of theatre acoustics mechanisms along the history. A lot of questions about them are without answer yet.

Finally, we have consulted a wide actual bibliography and several ancient treatises about theatres, and we have establish the bases to carry out later interest researches.

References

[1] G. Saunders, "Treatise on theatres", London (1790)

[2] A. Barba, A. Giménez, R. Cibrián, S. Cerdá, J. Romero, R. Lacatis, "Study of the Italian Style Theatre's acoustic performance throughout the research job carried out in the "Teatro Principal"of Valencia", 19th International Congress on Acoustics, Spain (2007)

[3] Archivo del Departamento de Arquitectura de la Diputación Provincial de Valencia, 1989

[4] H. Arau, "ABC de la Acústica Arquitectónica", Barcelona, CEAC, 185-187, 201-215 (1999)

[5] P. Patte, "Essai sur l'architecture thêatrale", Paris (1782)

[6] M. Forsyth, "Buildings for music", Cambridge, Cambridge University Press (1985)

[7] G. C. Izenour, "Theater Design", U.S.A., McGraw-Hill Book Company (1977)